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Original article

Ecological Assessment Battery for Numbers (EABN) for brain-damaged patients: Standardization and validity study

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ABSTRACT

Objectives: Number-processing may be altered following brain injury and might affect the everyday life of patients. We developed the first ecological tool to assess number-processing disorders in brain-injured patients, the Ecological Assessment Battery for Numbers (EABN; in French, the BENQ). The aim of the present study was to standardize and validate this new tool.
Material and methods: Standardization included 126 healthy controls equally distributed by age, sex and sociocultural level. First, 17 patients were evaluated by the EABN; then scores for a subgroup of 10 were compared with those from a French analytical calculation test, the Évaluation Clinique des Aptitudes Numériques (ECAN). The concordance between the EABN and the ECAN was analyzed to determine construct validity. Discrimination indexes were calculated to assess the sensitivity of the subtests.
Results: Standardization highlighted a major effect of sociocultural level. In total, 9 of 17 patients had a pathological EABN score, with difficulties in telling time, making appointments and reading numerical data. The results of both the EABN and ECAN tests were concordant (Kendall's $w = 0.97$). Finally, the discriminatory power was good, particularly for going to the movies, cheque-writing and following a recipe: scores were > 0.4.
Conclusion: The EABN is a new tool to assess number-processing disorders in adults. This tool has been standardized and has good psychometric properties for patients with brain injury.

1. Introduction

Numbers play a major role in our daily lives. Number-processing may be altered after a brain injury. Hécaen et al. presented the first classification of acalculia syndromes [1]. Later, theoretical calculation models were developed, particularly by McCloskey and Caramazza [2] and Dehaene et al. [3].

Routine evaluation of cognitive functions [4] revealed a significant gap between patients' performance in analytical laboratory-based tests and in daily life [5–7]. Awareness of such a discrepancy has resulted in studies of the notion of ecological validity, which has become an increasingly relevant concept after the revision of the International Classification of Functioning, Disability and Health (ICF) [8]. The ICF reflects a recent evolution from a medical and rehabilitative approach to disability toward an ecological approach [9]: disability is based on cognitive deficits as well as interactions with the environment. Therefore, evaluation of disability is insufficient when focusing on only a simple assessment of the person's analytically investigated cognitive dysfunction or impairment.

The current analytical tools for cognitive evaluation of number-processing [10] are the EC301R-F [11,12], the Talk, Listen Connect: Phase II (TLC2) [13,14] and the Évaluation Clinique des Aptitudes Numériques (ECAN) [15], the latter developed by Auzou [15]. These tests facilitate identification of impaired processes, but to our knowledge, no study has investigated an "ecological" tool. Both approaches are complementary: ecological evaluation aims to quantify the impact of the deficits highlighted by analytical evaluation. Ecological assessment often places the patient in a more demanding situation in terms of the attention cost or the strategies required to reach the goal set by the examiner [16–18]. As a result, the executive functions are solicited to a greater extent. The same patients may show different performance

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patterns during ecological and analytical evaluation. At times, the routine nature of some daily tasks can help the patient perform them. As regards to their complaints, Darrigrand et al. [19,20] studied the scores of 127 aphasic patients on the Bordeaux Scale of Verbal Communication. Disorders were particularly predominant in writing cheques or using bank cards (57% of patients). This finding underscores the need for new evaluation tools that can objectify patients' problems.

The Ecological Assessment Battery for Numbers (EABN) [21] is an ecological protocol consisting of 18 subtests grouped together in 8 main tests. The tool was constructed to underscore the number-processing difficulties encountered in daily life by adults with brain injury. Test construction was based on neuropsychological number-processing models [2,3] and involved the difficulties brain-injured patients have in daily life, particularly with numbers. The first version of the test, involving 83 subjects, was stratified and standardized, and resulted in data for the performance of 12 aphasic patients [22]. This first study highlighted the sensitivity of the EABN to capture global changes as well as specific disorders experienced by aphasic patents. We analyzed the validity of this version [23–25] by consulting various experts (occupational therapists, neuropsychologists and speech therapists), who graded the relevance of the different tests. The recorded scores underlined the good validity of most of the tests, and the expert judgments were concordant. Inter-judge reliability was analyzed, with slight variability observed. Finally, the study showed good discriminatory power for most of the tests, except those pertaining to following a recipe, going to the movies, and telling time.

However, the study revealed a number of limitations; some tests were considered by experts to be less relevant than others. Experts also considered that certain supports needed improvement and that some of the rating criteria were insufficiently precise and therefore likely to produce subjectivity. To enhance the psychometric qualities of the EABN and using previously mentioned results, we endeavored to modify some of the tests. We eliminated those that received the poorest grades from the expert judges and modified some of the rating criteria to improve inter-judge reliability and increase the discriminatory power of the least sensitive tests.

The aim of the present work was to study the standardization and provide an initial validation of the number-processing assessment battery EABN in daily life situations. The secondary aim was to study the effect of demographic variables on the scores of a healthy control population, establish stratified standards, and compare the performance of a group of brain-injured patients on the EABN and an analytical test used as a gold standard.

2. Patients and methods

2.1. EABN

The EABN [21] is an ecological test battery addressing the use of numbers in daily life; it consists of 8 tests (Table 1) corresponding to common situations in everyday life involving numbers: telling time, going shopping, writing a cheque, writing down contact information, cooking etc. All tests and subtests are timed; however, subjects are asked not to take time measurement into account and to proceed as usual, thereby not being under pressure. The maximum total score is 40. The EABN material includes the rating sheet and the testing handbook, a chronometer, a calculator, a schedule, and play money. The complete test battery is completed individually by control subjects. The test generally takes place in a calm room and lasts 10 to 25 min. In most cases, professionals in charge of the EABN test went to the homes of control subjects.

Table 1
Tests and maximum number of points given for each Ecological Assessment Battery for Numbers (EABN) test and subtests.

Tests	Max score	Subtests
Telling time	4	Analog dials Digital dials
Shopping	9	Evaluating the prices of everyday items Approximate calculation of a total amount Cash payment of an exact amount of money Verification with a calculator a total amount
Cheque-writing	6	Calculating a percentage Payment by cheque an amount of money specified orally
Making appointments	9	Calculating a duration Placing a date and an hour on a schedule Writing down dictated contact information Providing one's own contact information
Going to the movies	4	Choosing an hour according to temporal data Verifying and calculating the change given
Composing a digital code	1	Composing a digital code given orally in digicode
Following a recipe	2	Placing specified quantities on a scale
Reading numerical data	5	Reading contact information Reading sentences containing numerical data

2.2. Standardization of the EABN

The subjects included for the standardization phase were 20 to 79 years old with equal distribution by age (20–39, 40–59 and 60–79 years), sex and sociocultural level (SCL1: $\leq$ French certificate of higher education; SCL2, baccalaureate degree; SCL3, higher studies). Subjects had to understand and use the French language and have no abnormal neurological or psychiatric history. We produced descriptive (mean, SD, percentile 5) and inferential statistics using Student's *t* test to estimate the effect of demographic variables on the EABN score and to establish standards according to the recorded effects. We preliminarily determined that if the score distribution were non-normal, the 5th percentile would be considered the pathological threshold.

2.3. Concurrent validity analysis

We performed a validity study [26] with brain-injured patients who were hospitalized between September 2011 and December 2012 in the physical and rehabilitation medicine unit of La Pitié-Salpêtrière Hospital, Paris. Inclusion criteria were age 20 to 79 years, with no sensory or motor disability that disallowed taking the tests.

The patients were evaluated by both the EABN and a French analytical calculation test, the ECAN [15]. The ECAN is an analytical battery designed to test abilities in calculation and number-processing. It was developed and standardized by Auzou et al. according to the French language adaptation of the Number-Processing and Calculation (NPC) battery [27]. It includes 35 tasks assessing the different abilities in counting, the different aspects of number comprehension, numerical transcoding, calculation, arithmetic reasoning and conceptual knowledge. It assesses the calculation skills needed for 4 operations (simple fact retrieval, rule-based processing, mental calculation, written calculation) as well as problem resolution. The ECAN is more complete and provides more accurate evaluation of impaired processes than the

Table 2
Standardization results for EABN tests and effect of demographic variables.

Tests	Mean ± SD	% of subjects recording		Effect of age	Effect of sex	Effect of SCL
		Min score	Max score			
Telling time	3.86 ± 0.33	0	96	$P < 0.05$	NS	$P < 0.0001$
Shopping	7.75 ± 1.23	0	26	$P < 0.05$	NS	$P < 0.0001$
Cheque-writing	4.91 ± 1.25	0	43	$P < 0.05$	NS	$P < 0.0001$
Making appointments	8.78 ± 0.48	0	79	NS	NS	NS
Going to the movies	3.29 ± 1.06	1	62	NS	NS	$P < 0.0001$
Composing a digital code	0.99 ± 0.09	1	99	NS	NS	NS
Following a recipe	1.18 ± 0.65	13	32	NS	NS	$P < 0.0001$
Reading numerical data	4.82 ± 0.44	0	85	NS	NS	$P < 0.0001$
TOTAL	35.58 ± 3.47	0	8	NS	NS	$P < 0.0001$

SCL: sociocultural level; NS: not significant.

EC301 and has been standardized with 423 healthy control subjects. It is based on 4 main areas: knowledge of numbers, transcoding, calculation and common knowledge of numbers. All tests are timed. They differ in several ways from the NPC: there are more items for the transcoding tests but some common items for different tasks, thereby allowing comparison of performance. Finally, the NPC approximate test, which practically all control subjects failed, has been replaced by a test derived from the Stanescu-Cosson test [28].

To study the degree of concordance between the ecological battery (EABN) and the analytical battery (ECAN), our reference battery, we calculated Kendall's w coefficient [29]. The Kendall w coefficient ranges from 0 to 1: the closer to 1, the greater the degree of concordance. The objective was to classify patients by rank on the test based on comparisons of the recorded grades.

2.4. Construct validity analysis

To establish construct validity, we analyzed the discriminatory power of each subtest. We calculated the discrimination indexes corresponding to the difference between the difficulty indexes of the 2 extreme groups, using the standardization data and the data collected from patients. The values for the P index for relative difficulty of the items range from 0 to 1: values close to 0 indicate an item for which few subjects successfully performed, and values close to 1 denote an item for which a high proportion of subjects successfully performed. When an item is rated on a scale containing several points, the difficulty index corresponds to the mean rating achieved for this item by the subjects as a whole. The mean rating for the item is divided by the maximum grade: for example, if the maximum grade for the item is 5, the mean grade for that item is divided by 5.

The P index equals the total sum of the ratings divided by the number of subjects. The item discrimination index D corresponds to the difference between the difficulty index for an item with regard to the "strong" group ($P+$) and the difficulty index for the "weak" group ($P-$). The larger the difference in D, the more the item discriminates between subjects with a high total score and those with a low total score. The "strong" group consists of subjects with a total score placing them in the upper 27% of the total population, and the "weak" group consists of those whose score places them in the lower 27% [30]. To constitute these groups, we used the detailed standardization data ($n = 126$) and the results recorded for patients ($n = 17$), for a relatively large sample.

The discrimination index D can take on any value from –1 to +1. A value of zero means that a given item was as successfully negotiated by subjects with a low total score as by those with a high total score. A negative value means that with respect to an item, weaker subjects were more successful than stronger subjects. A discrimination index $D > 0.4$ is very good; 0.2 to 0.4, good; 0.1 to 0.2, average; and < 0.1 or negative, insufficient.

3. Results

3.1. Standardization

We included 126 healthy control subjects equally distributed by age, sex and sociocultural level in standardization. Sex had no effect and age only a marginal in only 3 tests, not in the total score (Table 2). By contrast, sociocultural level had a profound effect in 6 tests and in the total score. Therefore, we established stratified standards by sociocultural level (Tables 3, 4 and 7). The cut-off point for the total score ranged from 27.5 to 34/40 by sociocultural level (SCL). Performance varied markedly, especially for SCL1 (Table 4). We found no floor or ceiling effect in the total score, in that only 8% of the control subjects showed a maximum score, and none showed a minimum score.

Table 3
Stratified standards for the EABN tests and total scores.

Test	Max score	SCL1			SCL2			SCL3		
		Mean ± SD	95% CI	c 5	Mean ± SD	95% CI	c 5	Mean ± SD	95% CI	c 5
Telling time	4	3.7 ± 0.5	[3.55; 3.82]	3	3.9 ± 0.3	[3.82; 3.97]	3.5	4 ± 0.1	[3.93; 4.00]	4
Shopping	9	7.3 ± 1.4	[6.90; 7.71]	4.5	7.6 ± 1.2	[7.29; 7.99]	5.5	8.3 ± 0.9	[8.01; 8.57]	6.5
Cheque-writing	6	4.2 ± 1.6	[3.76; 4.71]	1	5.1 ± 1	[4.84; 5.43]	3	5.3 ± 0.8	[5.08; 5.57]	4
Making appointments	9	8.8 ± 0.5	[8.65; 8.98]	8	8.8 ± 0.5	[8.65; 8.98]	7.5	8.8 ± 0.5	[8.65; 8.98]	8
Going to the movies	4	2.9 ± 1.3	[2.48; 3.24]	1	3.3 ± 1	[2.95; 3.56]	1	3.7 ± 0.7	[3.54; 3.94]	2
Composing a digital code	1	1 ± 0.2	[0.92; 1.02]	1	1 ± 0.2	[0.92; 1.02]	1	1 ± 0.2	[0.92; 1.02]	1
Following a recipe	2	0.9 ± 0.6	[0.75; 1.08]	0	1.1 ± 0.7	[0.85; 1.25]	0	1.6 ± 0.6	[1.40; 1.73]	1
Reading numerical data	5	4.7 ± 0.6	[4.47; 4.84]	4	4.9 ± 0.3	[4.81; 4.98]	4	4.9 ± 0.3	[4.81; 4.99]	4
Total	40	33 ± ±4.1	[32.14; 34.63]	27.5	36 ± 2.7	[34.90; 36.54]	30.5	38 ± 1.8	[37.07; 38.17]	34

95% CI: 95% confidence interval; c 5: 5th percentile; sociocultural level (SCL): SCL1 (≤ French certificate of higher education), SCL2 (baccalaureate), SCL3 (higher studies).

Table 4
Stratified standards for test-taking times for the EABN, expressed in seconds.

Subtest	SCL1		SCL2		SCL3	
	Mean ± SD	c 95	Mean ± SD	c 95	Mean ± SD	c 95
Telling time	27 ± 12	40	25 ± 8	41	23 ± 6	32
Shopping	123 ± 69	235	98 ± 43	191	89 ± 31	145
Cheque-writing	101 ± 51	215	87 ± 30	134	71 ± 21	111
Making appointments	137 ± 78	269	108 ± 35	148	96 ± 31	131
Going to the movies	63 ± 41	128	54 ± 36	125	40 ± 21	74
Composing a digital code	4 ± 2	8	4 ± 2	8	3 ± 1	6
Following a recipe	57 ± 28	107	48 ± 25	93	40 ± 32	97
Reading numerical data	15 ± 5	26	14 ± 5	17	14 ± 4	24
Total	525 ± 243	1128	437 ± 137	694	376 ± 94	514

c 95: 95th percentile (can be considered the pathological threshold).

Table 5
Description of the 17 patients testing the EABN.

Patient	Age, *y*	Sex	SCL	Pathology	Laterality of the injury	Laterality of patient	Time since accident (months)
1	53	M	2	Capsular-thalamic stroke capsthalamique	Left	Right	6
2	67	F	3	MCA stroke	Left	Right	4.5
3	34	M	3	HT	Right	Right	9
4	64	F	1	MCA stroke	Left	Right	8
5	20	M	2	HT	Left	Right	8
6	62	F	1	MCA stroke	Left	Right	5
7	43	F	3	MCA stroke	Left	Right	20
8	46	M	3	Carotid junction stroke	Right	Right	10
9	25	F	3	MCA stroke	Right	Right	2
10	64	M	2	MCA stroke	Left	Right	9
11	54	F	1	MCA stroke	Left	Right	3
12	70	M	1	MCA stroke	Left	Ambidextrous	5
13	47	F	2	MCA stroke	Right	Right	3
14	67	M	3	MCA stroke	Left	Left	85
15	63	M	1	MCA stroke	Right	Right	0.5
16	63	M	1	MCA stroke	Right	Right	3
17	28	F	3	MCA stroke	Left	Right	9

M: man; F: female; HT: head trauma; MCA: middle cerebral artery.

Table 6
Total scores for 10 patients on the EABN and Évaluation de Calcul et des Activités Numériques (ECAN).

Patient	EABN	ECAN
1	38	502
2	6	132
3	37.5	504
4	8	205
5	35.5	506
6	11.5	314
7	33.5	466
8	33.5	462
9	38.5	525
10	34.5	468

3.2. Patient results

We included 17 patients (8 women; mean age 51 ± 16.97 years, range 20 to 70 years; Table 5); 15 had had a stroke and 2 a traumatic brain injury. Most of the brain lesions were in the left hemisphere. In total, 9 had a total EABN score considered pathological (mean 26.75 ± 11.29). We found major heterogeneity in the score distribution. The mean time for the test was 20 min; for 12 patients, the time was considered pathological. The most commonly failed tests were telling time, making appointments and reading numerical data – in general, those involving transcoding, especially reading Arabic numerals aloud. We found 2 overall profiles according to injury lateralization. Patients with a left brain injury (LBI) (n = 11) had more difficulties telling time and reading numerical data. Patients with a right brain injury (RBI) (n = 6) had difficulties for making appointments and going to the movies.

3.3. Concordance between EABN and ECAN

Ten patients underwent analytical and ecological testing. Rank correlation (Kendall's w) between the ecological (EABN) and analytical (ECAN) results (Table 6) was high (w = 0.97) and statistically significant. The 2 tests classified patients in the same

Table 7
Stratified standards by process.

Process	Max grade	SCL1		SCL2		SCL3	
		Mean ± SD	c 5	Mean ± SD	c 5	Mean ± SD	c 5
Transcoding	25	23.18 ± 1.76	20	24.13 ± 1.12	22	24.24 ± 0.88	23
Mental calculation	9	5.92 ± 2.32	2	7.32 ± 1.69	4	7.93 ± 1.20	6
Estimate	6	4.17 ± 1.03	2	4.52 ± 0.91	3	5.26 ± 0.81	4

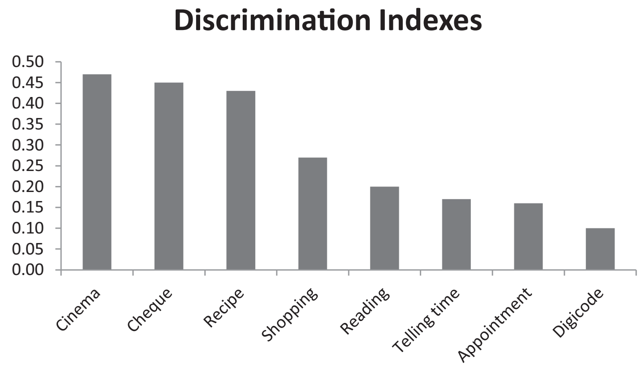

Fig. 1. Discrimination indexes for the Ecological Assessment Battery for Numbers (EABN) subtests: going to the movies (cinema), cheque-writing (cheque), following a recipe (recipe), shopping, reading numerical data (reading), telling time (time telling), making appointments (appointment), composing a digital code (digicode). See Table 1 for descriptions of the tests.

order: patients with poor scores on the EABN also had poor scores on the ECAN.

3.4. Discriminatory power of the EABN subtests

The discrimination index was very good (> 0.4) for 3 subtests – going to the movies, cheque-writing, and following a recipe; good (0.2–0.4) for shopping and reading numerical data and moderate for telling time and making appointments. (Fig. 1)

4. Discussion

The present study aimed to standardize and study the EABN, a battery to assess number-processing disorders in brain-injured patients. Standardization with a group of 126 healthy control subjects highlighted a significant effect of sociocultural level as well as analytical calculation batteries in adults. In agreement, educational level has a major influence on the performance of healthy subjects in the TLC2 test, with the effect of age less important [13,14]. However, standardization of the ECAN test in 2012 by Auzou et al. with 263 healthy control subjects showed an effect of age on performance. Finally, in a study by Deloche et al. [12] on the performance of illiterate or subjects with low sociocultural level, in addition to the expected effect of sociocultural level, sex had a significant effect, which was not the case in our study.

Nine of our 17 brain-injured patients had a pathological EABN score. Therefore, a systematic screening of subjects for calculation difficulties and their impact after a brain injury seems relevant. Patient results on the EABN agreed with those reported by Dellatolas et al. [11] on the performance of brain-injured patients in the EC301 tests. In that study, most of the patients with LBI had difficulties in tasks of counting, transcoding and written calculations. Accordingly, patients with LBI in our study also showed difficulties in telling time and reading numerical data, both of which involve transcoding. RBI patients had difficulties in estimation tasks and placing numbers on a scale. In our study, RBI patients had difficulties making appointments and going to the movies, both of which involve mental calculation. In view of these different results, the EABN may be considered a sensitive tool for measuring the most common difficulties encountered by brain-injured patients and may be well suited for assessing such patients.

For some patients, the total score corresponded to the standard score, yet the duration of the testing was abnormally long. Patients' timing allows for identifying those more likely to be limited in function because of slow execution of tasks and, consequently, those unlikely to successfully perform in everyday life. However, to provide a more accurate description of the difficulties in daily life activities by type of brain injury, the performances should be analyzed in a larger population of patients.

Given the concordance between the EABN results and the reference analytical tool ECAN, the EABN may be considered a valid tool. Concurrent validity was good. Deloche et al. [12] demonstrated a strong relationship between the scores on the EC301 (calculation and number-processing assessment) and on a questionnaire about subjects' number-based daily life activities, thereby confirming the satisfactory ecological validity of their test (assuming that their questionnaire was valid). For the EABN, the discriminatory power of the subtests was high. We found no discriminatory value < 0.1 or a negative value. Therefore, all of our subtests can be considered screening subtests, and we noted an improvement as compared with the previous version of the battery: for the recipe making and movie-going tests, the discrimination indexes increased from 0.2 and 0.17, respectively, for the previous version to 0.45 and 0.47 for the new version.

In the final analysis, a test is considered valid when research demonstrates that it effectively measures whatever it is supposed to measure. Thus, one may never assert that per se, a given test is valid in absolute terms [26].

5. Conclusion

The EABN is a newly introduced and standardized ecological battery addressing calculation difficulties for brain-injured patients. The psychometric properties of the EABN are satisfactory for its usefulness in practice to quantify the impact of problems patients have processing numerical data in everyday life. As well, the properties justify providing guidelines for future rehabilitation programs addressing cognitive disorders that remain to be adequately evaluated.

Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.

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